THE EFFECT OF COMBINATIONS OF ORGANIC MATERIALS AND BIOFERTILISERS ON PRODUCTIVITY, GRAIN QUALITY, NUTRIENT UPTAKE AND ECONOMICS IN ORGANIC FARMING OF WHEAT

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Abstract

Organic farming often has to deal with a scarcity of readily available nutrients, and this is in contrast to chemical farming which relies on soluble fertilisers. The present study was conducted to ascertain the effect of different combinations of organic manures, rice residues and biofertilisers in organic farming of wheat. The field experiments were carried out on the research farm of Indian Agricultural Research Institute (IARI), New Delhi in 2006-07 and 2007-08. Treatments consisted of a control (no fertiliser) and six fertiliser treatments, namely, farmyard manure (FYM), vermicompost (VC), FYM + rice residue (RR), VC + RR, FYM + RR + biofertilisers (B), and VC + RR + B. FYM and VC were applied on nitrogen basis (60 kg ha^{-1}), whereas RR was applied at 6 t ha^{-1}. For biofertilisers, *Azotobacter*, cellulolytic culture (CC) and phosphate solubilising bacteria (PSB) were used. The combinations of FYM + RR + B and VC + RR + B resulted in the highest increased growth and yield attributing characters of wheat and increased grain yield of wheat over the control by 81% and 89% (Year 1 & Year 2), and net return by 82% and 73% . These combinations were significantly superior to all other combinations for all the growth and yield parameters, yield, net profit and grain quality of wheat. The results of this study show that VC + RR + B was the most productive treatment, while FYM + RR + B was the most economical treatment with respect to increasing net profit. This was because of the higher price of vermicompost compared with FYM. Both of these combinations resulted in improved grain quality and nutrient uptake by grain. The present study thus indicates that a combination of FYM + RR + biofertilisers or VC + RR + biofertilisers hold promise for organic wheat farming.

Key words: Grain quality, nutrient uptake, organic farming, wheat, economics.

Introduction

Wheat is the second most important cereal crop in India, after rice, both in terms of area and production. The country has witnessed spectacular progress in wheat production and is the second largest producer of wheat next to China (Kumar and Yadav, 2006). Organic farming often has to deal with a scarcity of readily available nutrients in contrast to inorganic farming which relies widely available on soluble fertilisers. The aim of nutrient management in organic systems is to optimise the use of on-farm resources and minimise losses (Kopke, 1995). Incorporation of straw results in the recycling of a sizable amount of plant nutrients. For example rice straw accounts for about 35-40% N, 12-17% of P and 80-90% of K removal by a rice crop (Sharma & Sharma, 2002). The sole recycling/incorporation of cereal straw, which is available *in situ* is not possible due to two main reasons, (i) in many parts of the Indo Gangetic plains, in the Terai of Nepal and in China, straw is used as bedding for animals, fuel and other uses (Prasad & Power, 1991), and (ii) because of the wide C:N ratio (70 or above), it can result in a temporary immobilisation of native soil and applied mineral N (Aulakh et al., 2000). A number of researchers (Pandey et al., 1985; Rajput & Warsi, 1995; Prasad et al., 2004) have reported increased yield of rice and /or wheat by the incorporation of wheat/rice residue, while others (Sharma, 2005; Singh & Sharma, 2000) have failed to do so. Hence there is an urgent need to develop a suitable technology to use crop residues in the organic farming of wheat. Mixing the crop residues of cereals with well decomposed farmyard manure/compost/vermicompost or crop residue of legumes reduces the C:N ratio so as to overcome the adverse effect of N immobilisation. Hence, the present study was conducted to study the effect of different combinations of organic manures, rice residues and biofertilisers in the organic farming of wheat.

Materials and methods

A field experiment was conducted at the research farm of the Indian Agricultural Research Institute, New Delhi in 2006-2007 and 2007-2008. The farm is situated at 28.4° N and 77.1° E at an elevation of 228.6 metres. The soil had a moderate level of organic C (5.1 mg kg^{-1} soil), available phosphorus (8.42 mg kg^{-1} soil) and available potassium (108.87 mg kg^{-1} soil), and was low in available nitrogen (73.1 mg kg^{-1} soil), and pH was 8.16. In 2006-07, the minimum and maximum temperature ranged from 3.4-7º C and 28.9- 31.4 °C, respectively, with a total rainfall of 145.6 mm received during the cropping season. During 2007-08, it was 3.2-6.9 °C and 29.8- 33.9 °C respectively, and a total of 46.9 mm rainfall was received.

The treatments consisted of a control (no fertiliser applied) and six combinations of organic manures, crop residues and biofertilisers: (1) farmyard manure equivalent to 60 kg N ha^{-1} (FYM); (2) FYM + rice residue of preceding crop @ 6 t ha^{-1} (RR); (3) FYM + RR + biofertilisers (B); (4) vermicompost equivalent to 60 kg N ha^{-1} (VC); (5) VC + RR and (6) VC + RR + B. The experiment was laid out in a randomised block design with six replications.

For biofertilisers, *Azotobacter,* cellulolytic culture and phosphate solubilising bacteria (PSB) were used in wheat. Farmyard manure used in the experiment was well decomposed for 6-8 weeks. It contained 6100-6200 mg kg^{-1} N, 2500-2700 mg kg^{-1} P, 3000-3100 mg kg^{-1} K, 11-12mg kg^{-1} Mn, 39-40 mg kg^{-1} Zn, 2.6-2.7 mg kg^{-1} Cu, 21-22 mg kg^{-1} Fe and had a C:N ratio of 23-24. VC contained 11900-12000 mg kg^{-1} N, 6265-6300 mg kg^{-1} P, 6900-7000 mg kg^{-1} K, 37-38 mg kg^{-1} Mn, 86-88 mg kg^{-1} Zn, 8-9 mg kg^{-1} Cu, 57-58 mg kg^{-1} Fe and had a C:N ratio of 71-72. The nutrients added through various organic materials are given in Table 1.

Rice residue, FYM and VC were incorporated before sowing wheat. Cellulotic culture containing four fungi, *Aspergillus awamori, Trichoderma viride, Phanerochcete chrysosporium* and *Aspergillus wolulens* was inoculated at the time of residue incorporation, whereas *Azotobacter* and *Pseudomonas striata* (a PSB) were used to inoculate the seeds as per the treatments. After the harvest of rice, the field was irrigated and at the optimum soil moisture level (15-20% of field capacity), the required quantity of FYM, VC and crop residue was uniformly spread on the relevant plots and incorporated with tractor drawn heavy disc. Wheat was irrigated four times in the first year and five times in the second year at critical stages of crop growth. In both years, wheat was harvested in the fourth week of April, 19 weeks after sowing.

Table 1. Quantity (kg/ha/year) of N, P, K, Fe, Zn, Mn and Cu added through organic materials and biofertilisers under various treatments.

Treatments	N	P	K	Fe	Zn	Mn	Cu
Farmyard manure (FYM)	60	25-27	30-31	0.21-0.22	0.40-0.41	0.12	0.03
Vermicompost (VC)	60	31-32	35-36	0.29-0.30	0.43-0.44	0.19	0.04
FYM + Rice residue (RR)	83	28-29	124-125	2.31-2.32	0.58-0.61	0.56-0.59	0.13
VC + RR	83	36-37	128-129	2.39-2.51	0.61-0.65	0.46-0.63	0.14
FYM+RR+Biofertilisers (B)	108	41-42	124-125	2.31-2.32	0.58-0.61	0.56-0.59	0.13
VC + RR + B	108	48-89	128-129	2.39-2.52	0.61-0.65	0.46-0.63	0.14

Grain and straw samples of wheat were collected at harvest and analysed for total N using a micro-Kjeldahl method, while total P and potassium (K) were determined using sulphuric-nitric-perchloric acid digest (Prasad 1997). Nutrient removal was estimated by multiplying the N, P and K concentration (%) of grain and straw with their respective yield (kg ha^{-1}) and total nutrient uptake was calculated from the sum of grain and straw nutrient uptake.

Kernel hardness index was determined using the Single Kernel Characterization system 4100 from Perten Instruments, Australia. All dockage was removed from the sample using a seed cleaner and 200 g of seed was used for the analysis. The values of kernel hardness, moisture and grain weight were recorded for 100 seeds of each sample. The Sodium Dodecyl Sulphate (SDS)-sedimentation test (Dick & Quick, 1983, cited in Misra et al., 1998) was used to determine gluten strength.

The cost of cultivation of wheat was calculated on the basis of prevailing rates (Directorate of Economics and Statistics, 2008) of inputs and gross income was calculated on the basis of procurement price of organic wheat grain (Export-import Bank of India, 2007; Export-import Bank of India, 2008) and prevailing market price (Directorate of Economics and Statistics, 2008) of wheat straw. The income was obtained by subtracting cost of cultivation from gross income, i.e. net income = gross income – cost of cultivation.

The data relating to each variable were analysed using Analysis of Variance (Cochran & Cox, 1957). Critical difference (CD) at 5% level of significance was calculated for comparing the mean of difference presented in the summary table.

Results and discussion

Growth, yield attributes and yields

Farmyard manure contains primary, secondary and micronutrients. Thus, application of FYM significantly increased total biomass, number of spikes, spike length and grains per spike in both the years of study (Table 2) which led to a significant increase in grain and straw yield of wheat with FYM application over the control (Table 3). The grain yield increased due to FYM application by 22% compared to the control in the first year and 64% in the second year. FYM applied to wheat during the first year is expected to leave a sizeable amount of nutrients in the soil, and potentially improve the physical and biological properties of soil during the second year as compared to during the first year. Behera et al. (2007) reported that the application of available organic sources, particularly FYM and poultry mature along with the full recommended dose of mineral fertilisers to wheat was essential for improving productivity of wheat-soybean system. Thakur & Patel (1998), Tripathi & Gehlot (1999), Singh & Agarwal (2004) also reported a beneficial effect of FYM on wheat.

Vermicompost (VC) in wheat resulted in a significant increase in all of the growth parameters and yield attributes except test weight in the first year, which led to a 28.9-76.1% increase in grain yield and a 25-70% increase in straw yield over control. Ranva & Singh (2006) reported the application of vermicompost at 7.5 or 10 t ha^{-1} gave higher yields than 10 t ha^{-1} FYM.

The combination of FYM + RR was better than FYM alone for improvement in growth and yield attributes of wheat which resulted in 0.50-0.54 and 0.7-3.2 t ha^{-1} increase in grain yield and straw yield, respectively over FYM application. Kler et al. (2007) reported that grain yield, grains per ear and thousand grain weight were significantly higher where 10 t FYM ha^{-1} with 80% of the recommended mineral fertiliser dose, and with crop residue incorporation/mulching and the recommended fertiliser dose. The combination of VC + RR was significantly better than VC alone for the improvement in growth and yield attributes of wheat which resulted in an 18 and 12% (Year 1 & Year 2), and an 18 and 10% increase in grain and straw yield, respectively, over VC alone (Table 3).

Inoculation of *Azotobacter* + PSB with FYM + RR significantly increased number of grains per spike and test weight in both the years over FYM + RR which resulted in an 11-13% higher increase in grain yield and an 8-10% higher increase in straw yield over FYM + RR. Maity (2006) reported that the grain yield of wheat at 75% recommended dose of NP along with the application of FYM @ 10 t ha^{-1} and inoculation of PSB resulted in significantly higher yield even over the 100% recommended dose of NP. Inoculation of *Azotobacter* + PSB with VC + RR resulted in significant and non-significant increase in all the growth parameters and yield attributes of wheat over VC + RR alone which resulted in 10.6 and 6.9%% (Year 1 & Year 2) increase in grain yield, 6.9 and 4.2% increase in straw yield (Table 3). The increase in grain yield was related to the amount of nutrients added through various organic materials and biofertilisers under the different treatments (Table 1). FYM and vermicompost only, and no crop residue and biofertilisers had lower wheat grain yield that could be attributed to deficiency of required plant nutrients in those treatments.

Grain quality

Since the N, P, K, Zn, Fe, Mn and Cu concentration in wheat grain did not differ significantly in two years the mean data over two years are presented in Table 4. Application of FYM or VC significantly increased N, P, Cu and Mn concentration in wheat grain over control but did not affect the K, Zn and Fe Concentration of wheat grain significantly. The effects of FYM + RR and VC + RR were similar and significantly increased N, P, K, Cu and Mn concentration over control. The combinations of FYM + RR + B and VC + RR + B were at par and significantly increased N, P, K, Zn, Cu, Fe and Mn concentration in wheat grain over control. The increase in the nutrient concentration with FYM + RR + B or VC + RR + B was higher as compared to those obtained with other nutrient combination. The concentration of a particular nutrient in wheat grain was, thus, linked with the supply of that particular nutrient through organic materials applied in different treatments (Table 1). In other words, the combined use of materials and biofertilisers can produce the highest nutrient parameters of wheat grain. Ngoc Son et al. (2001) reported significant positive effects on the quantity of nutrient content due to organic and bio-fertilisers applied to soybean.

Table 2. Effect of different organic materials and biofertilisers on yield attributes of wheat.

Treatments	Spike (no. m^{-2})		Spike length (cm)		Grains $spike^{-1}$		Test weight (g)	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Control	317	339	9.4	9.1	31.3	31.0	38.0	37.9
Farmyard manure (FYM)	345	370	10.1	10.8	36.2	37.6	38.2	38.8
Vermicompost (VC)	350	378	10.3	11.1	38.3	39.2	38.2	39.1
FYM + Rice residue (RR)	352	383	10.2	11.1	38.7	39.7	38.3	38.9
VC + RR	359	395	10.5	11.6	40.3	41.3	38.6	39.5
FYM+RR+Biofertilisers (B)	366	395	10.5	11.6	40.5	41.7	38.7	39.6
VC + RR + B	371	404	11.0	11.9	42.2	42.9	38.9	39.8
SE	9.15	11.60	0.16	0.26	0.50	0.59	0.10	0.20
LSD (P = 0.05)	28.18	36.67	0.50	0.79	1.54	1.83	0.31	0.62

Table 3. Effect of different organic materials and biofertilisers on yields and harvest index of wheat.

Treatments	Grain (t ha^{-1})		Straw (t ha^{-1})		Harvest Index (%)	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Control	2.66	2.64	4.24	4.20	38.5	38.6
Farmyard manure (FYM)	3.25	4.32	5.04	6.71	39.2	39.3
Vermicompost (VC)	3.43	4.65	5.30	7.15	39.3	39.4
FYM + Rice residue (RR)	3.75	4.86	5.75	7.44	39.5	39.5
VC + RR	4.06	5.19	6.25	7.89	39.5	39.7
FYM+RR+Biofertilisers (B)	4.24	5.37	6.35	8.04	40.0	40.0
VC + RR + B	4.49	5.55	6.68	8.22	40.2	40.3
SE	0.09	0.11	0.16	0.17	0.17	0.22
LSD (P = 0.05)	0.29	0.36	0.49	0.54	0.52	0.67

The physical and cooking quality of wheat was also affected by different nutrient combinations. The data of two years indicated that hardness and sedimentation value of wheat grain were not significantly affected by FYM and VC application in both the years of study (Table 5). Kharub & Chander (2008) reported that protein content in wheat increased with increase in the rate of FYM, but the highest protein content (11-24%) was recorded for inorganic fertiliser. The sedimentation value of wheat grain was unaffected by FYM + RR and VC + RR application, but hardness of wheat grain was significantly increased over the control. The combinations of VC + RR + B in both of years and FYM + RR + B in the second year only significantly increased the sedimentation value of wheat grain over the control. Konvalina et al. (2009) reported that a low-input (organic) farming system was associated with a reduction in the yield and technological quality, expressed by a reduction in the crude protein content in grain and a reduction in protein swelling (sedimentation values). With an increase in applied N, there was an increase in the protein percent, sedimentation value and grain hardness (Zecevic et al., 2004). A similar effect of N on wheat grain was reported by Mattas et al. (2011).

Table 4. Effect of organic materials and biofertilisers on nutrient concentration of wheat grain.

Treatments	N (%)	P (%)	K (%)	Zn (ppm)	Cu (ppm)	Fe (ppm)	Mn (ppm)
Control	1.40	0.27	0.34	43.3	6.2	30.1	32.2
Farmyard manure (FYM)	1.56	0.29	0.37	45.3	7.3	32.3	35.7
Vermicompost (VC)	1.59	0.30	0.38	46.1	7.8	33.4	36.3
FYM + Rice residue (RR)	1.58	0.30	0.40	45.7	7.6	33.7	36.7
VC + RR	1.63	0.31	0.42	47.1	7.8	35.6	37.6
FYM+RR+Biofertilisers (B)	1.64	0.32	0.43	47.4	8.2	36.3	38.6
VC + RR + B	1.66	0.33	0.44	48.3	8.5	37.5	39.8
SE	0.05	0.005	0.01	1.29	0.28	1.94	1.14
LSD (P = 0.05)	0.16	0.015	0.05	3.97	0.86	5.99	3.51

Table 5. Effect of treatments on physical and cooking quality parameters of wheat grain.

Treatments	Hardness (HI)		Sedimentation value (ml)	
	2006-07	2007-08	2006-07	2007-08
Control	78.7	79.1	39.8	38.8
Farmyard manure (FYM)	81.5	82.1	39.5	40.0
Vermicompost (VC)	83.2	83.7	40.5	41.0
FYM + Rice residue (RR)	85.9	86.5	40.3	41.0
VC + RR	87.5	88.2	41.2	42.0
FYM+RR+Biofertilisers (B)	87.9	88.5	42.5	43.3
VC + RR + B	89.4	90.7	44.0	44.7
SE	2.24	2.34	0.96	1.07
LSD (P = 0.05)	6.91	7.22	2.96	3.32

Nutrient uptake

The application of FYM significantly increased the quantity of N, P, K, Fe, Mn and Cu removed by wheat grain over the control (Table 6). Singh & Agarwal (2004) reported that the application of 10 t ha^{-1} FYM in rice-wheat cropping system resulted in significantly higher N, P and K uptake as compared with the control. Vermicompost was superior to FYM with respect to P, K, Zn, Fe, Mn, and Cu removal by rice grain. The application of wheat residue with FYM or VC also resulted in a significant increase in nutrient uptake by wheat grain. Kachroo et al. (2006) reported that the incorporation of rice residues in wheat not only increased nutrient uptake compared to no residue incorporation, but it also increased the productivity and yield components of wheat. Similarly inoculation of biofertilisers along with FYM + RR or VC + RR significantly increased the quantity of nutrient removal by wheat grain. The increase in nutrient uptake may be due to an increase in available N, P and K contents in the soil, and improved soil structure for higher uptake of nutrients (Manna et al. 2001).

Table 6. Effect of organic materials and biofertilisers on nutrient uptake (g ha^{-1}) by wheat grain.

Treatments	N	P	K	Zn	Cu	Fe	Mn
Control	37.1	7.2	9.0	114.7	16.4	79.8	85.3
Farmyard manure (FYM)	58.9	11.0	14.0	171.2	27.6	122.1	134.9
Vermicompost (VC)	64.2	12.1	15.4	186.2	31.5	135.0	146.7
FYM + Rice residue (RR)	67.9	12.9	17.2	196.5	32.7	145.0	157.8
VC + RR	75.5	14.4	19.5	218.1	36.1	164.8	174.1
FYM+RR+Biofertilisers (B)	78.9	15.4	20.7	228.0	39.4	174.6	185.7
VC + RR + B	83.3	16.6	22.1	242.5	42.7	188.2	200.0
SE	2.3	0.4	0.8	0.3	0.2	0.2	0.1
LSD (P = 0.05)	7.2	1.1	2.3	0.9	0.5	0.6	0.4

Economics

The cost of cultivation of wheat in the first year varied from Rs. 20,610 ha^{-1} for the control to Rs. 37,770 ha^{-1} for VC + RR + B, and from Rs. 13,400 ha^{-1} for the control to Rs. 31,600 ha^{-1} for VC + RR + B in the second year. The application of FYM increased the cultivation cost by 64-63%, VC by 50-47%, FYM + RR by 60-55%, VC + RR by 45-43%, FYM + RR + B by 56-54% and VC + RR + B by 45-42%. The application of FYM significantly increased the net income of rice over control by Rs 2600-22,300 ha^{-1} (Table 7). Hargilas (2006) also reported an increase in the net income of wheat with FYM application. FYM and VC did not differ significantly in terms of net income of wheat. The application of FYM + RR gave significantly higher net profit for rice than FYM alone in both the years of the study. Similarly, VC + RR was significantly superior to VC alone. Inoculation of biofertilisers with FYM + RR and VC + RR also significantly increased net profit of wheat over FYM + RR and VC + RR, respectively. The application of vermicompost + rice residue + biofertilisers (*Azotobacter* + cellulolytic culture + PSB) was most productive and FYM + rice residue + biofertilisers was economical for nutrient need of wheat. Both these combinations resulted in higher improvement in grain quality and physical, chemical and

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biological properties of soil. The net return and benefit:cost ratio were highest in the case of FYM + RR + B (Table 7), which might be due to the lower cost of FYM in comparison with vermicompost in India.

Table 7. Effect of treatments on economics of cultivation of wheat.

Treatments	Cultivation cost (×1,000 Rs* ha^{-1})		Net return (×1,000 Rs ha^{-1})		Benefit:cost ratio	
	2006-07	2007-08	2006-07	2007-08	2006-07	2007-08
Control	12.7	13.4	31.5	34.3	2.48	2.55
Farmyard manure (FYM)	19.7	21.4	34.1	56.6	1.73	2.64
Vermicompost (VC)	25.2	28.4	31.6	55.5	1.25	1.95
FYM + Rice residue (RR)	22.7	24.4	39.4	63.2	1.73	2.59
VC + RR	28.2	31.4	39.0	62.1	1.38	1.97
FYM+RR+Biofertilisers (B)	22.8	24.6	47.1	72.1	2.06	2.93
VC + RR + B	28.3	31.6	45.7	68.2	1.61	2.15
SE	-	-	0.68	0.87	0.21	0.23
LSD (P = 0.05)	-	-	2.09	2.67	0.62	0.68

* Indian Rupees (Rs) Re.1 = US$ 0.018

Conclusions

The results of this study show that application of vermicompost + crop residue + biofertilisers (*Azotobacter* + cellulolytic culture + PSB) was the most productive treatment but FYM + crop residue + biofertilisers was the most economical treatment with respect to increasing net profit. This was because of the higher price of vermicompost compared with FYM. Both of these combinations resulted in improved grain quality and nutrient uptake by grain. The present study thus indicates that a combination of FYM + RR + biofertilisers or VC + RR + biofertilisers holds promise for the organic farming of wheat.

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